USE OF DIFFERENT ORDINATION TECHNIQUES FOR STUDYING HUMAN ACTIVITY IN HERBACEOUS SYSTEMS

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ABSTRACT

Multivariate ordination techniques are used to examine the response of different parameters for assessing human activity in herbaceous systems. Two prominent environmental gradients account for much of the variability in the abiotic factors. The first is defined by the soil clay content, and the second is connected to human induced degradation, which is expressed by a decrease in the soil matter content. Vegetation composition also responds to man-induced changes in the soil environment. However the use of vegetation composition as an assessment tool requires more information on plant ecophysiology. Diversity and maturity indices related to soil nematode communities seem to be good indicators of anthropic impact in these mediterranean systems. The efficacy of combining different ordination techniques for analysing and interpreting patterns in ecological data is shown.

RÉSUMÉ

Different techniques d'ordination multivariant sont appliquées à l'étude de l'influence anthropique sur des systèms herbaceuses. En ce qui concerne les facteurs abiotiques, le contenu en argile et en matière organique du sol, permettent d'expliquer les principals variations trouvées. La composition végétale réspond aussi aux changes experimentés dans le sol. Quelques indices basés dans des measures de la diversité et maturité des communautés des nematodes pouvaient être bons indicateurs de l'impact humaine dans ces systèms méditerranèens.

INTRODUCTION

In the last years the study of the effects of human activity on ecosystems has become a question of environmental, as well as social and economic concern. The intensity of this impact is positively correlated with human population pressure and is especially apparent in periurban areas. From the perspective of either basic or applied research, there is a major interest in making use of urban-rural type gradients for the assessment and understanding of ecological changes that accompany human settlements (Matson, 1990). Most of the concepts and methods used in ecology may be applied to the study of this new kind of perturbation (McDonnell and Picket, 1993; Pouyat et al., 1995). The main purposes of ordination techniques in ecology are summarising bulky data, interpreting observed variations in terms of environmental gradients and understanding the response of ecosystem components to environment. Gradients do not necessarily have physical reality as continua in either space or time, but may be a useful abstraction for explaining ecosystem response to man induced changes (Ter Braak and Prentice, 1988). In this work, we compare the suitability of several multivariate analysis techniques to evaluate the response of different ecological parameters involve in the characterisation of perturbation in herbaceous ecosystems developed in periurban areas. We aim at drawing up effective tools for the environmental assessment of these man-modified systems.

MATERIAL AND METHODS

Study area

The study was carried out in the influence area of the city of Madrid, which represents the paradigm of rural to periurban transformation experienced in the Iberian Peninsula in the last decades. The territory is characterised by a progressively wider surface of land used for the installation of infrastructures of production, transport and services as well as for waste disposal. Food production also involves systems very dependent on outside income of energy and matter.

To assure the maximum uniformity with regard to land physical and edaphic factors that could influence ecosystem development, the study was limited to the arkosic area (located south western of Madrid). Edaphic development processes are connected to the degree of stability or erosion of geomorphologic surfaces. Three major types of soil can be distinguished in the area: luvisols, cambisols and regosols, according to FAO classification (1988). These soil types represent a different evolution level with dynamic relationships among them. Moreover they represent a light gradient with regard to some soil physical and chemical factors (Monturiol and Alcalá del Olmo, 1990). Climate is of Mediterranean continental type, with an average annual rainfall of 450-600 mm, which concentrates in autumn and spring. Summer is dry and hot.

Sampling strategy

Four land-use systems were included in the study: i) traditionally managed grasslands; ii) abandoned traditional agricultural soils, named as "old-fields"; iii) intensively cultivated soils, presently under fallow as a consequence of European agriculture policy; iv) waste dumping sites. The sampling sites were selected on the basis of being representative of one of the land-use patterns mentioned. A total of 120 localities were sampled, which were divided into the 4 categories as follows: 49 grasslands, 21 old-fields, 25 fallow-fields and 25 samples corresponding to the superficial sealing cover of three urban waste disposal sites.

At each site, sampling point was randomly established. Soil samples were taken from the upper 0-15 cm., where more of the biotic interactions take place in these herbaceous Mediterranean ecosystems. Vegetation inventory was based on a sampling unit of 0.5 m x 1 m located at each of the sampling points.

Data collection

Soil physical and chemical analysis were carried out on 2mm mesh air-dried subsamples, with the exception of ammonium determination which used fresh soil, and soil bulk density measurement which was performed with unaltered soil aggregates. A total of 39 parameters were analysed in each of the samples following the methodology described by Hernández and Pastor (1989). These parameters relate with soil physical stability, soil water and air content, nutritional status and toxicity/salinity conditions.

Vegetation data collection consisted in the inventory of the herbaceous species and the recording of their percentage of surface cover. A total of 220 species were identified, and classified on the basis of available phytosociological information. Nematode identification and count was carried out on fresh soil samples after extraction in glucose gradient. Twenty different taxa were identified and classified into trophic groups. These data were used to calculate the following species diversity indices: Trophic Diversity Index (T) (Heip et al., 1988), Shannon-Index (H') (Pielou, 1977), transformed Shannon-Index (Magurran, 1988) and the Simpson Diversity Index (S) (Pielou, 1977). Moreover nematodes were classified with regard to their colonisation-persistence ability, which constituted the basis for the calculation of the maturity indices (Bongers, 1990).

Statistical analysis

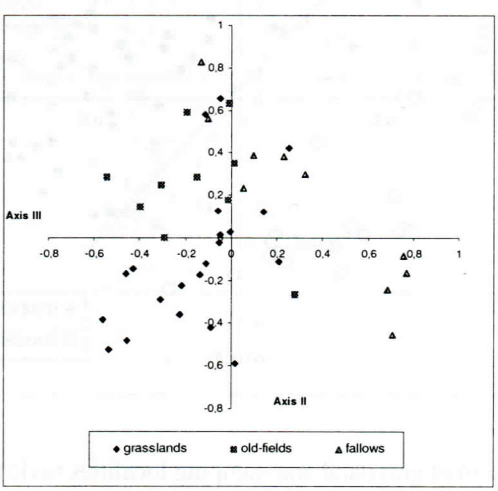
Three multivariate numerical techniques were applied to the data: Detrended Correspondance Analysis (DCA), Principal Component Analysis (PCA) and Multidimensional Scaling (MDS). Soil abiotic parameters were normalised before analysis. Chemical parameters had been previously logaritmically transformed. In the case of floristic and nematode data, only species present in more than 3 of the sites studied were included in the analysis, which resulted in a data-matrix of 120 localities x 146 species for vegetation analysis and of 120 localities x 19 nematode taxa.

RESULTS AND DISCUSSION

Soil abiotic factors

Both PCA and MDS ordination techniques proved to be adequate for analysing the effect of anthropization on soil abiotic factors. Figure 1 shows the ordination of grassland old-field and fallow localities in the space defined by PCA axis I and II. A similar interpretation can be made of the joint ordination analysis grassland, old-field and fallow-field samples. The percentage of variance explained by the three first axis of a PCA (21, 12 and 10% respectively) equals the value of the previous analysis.

Figure 1. Ordination of grassland, old-field and fallow localities (axis II and III of PCA)



The first PCA axis represents a soil granulometric composition related gradient, which, of course, cannot be addressed to anthropization but to natural edaphomorphogenesis processes. It distinguishes between sandy and clayey soils. Other soil factors associated to the clay content, such as the water holding capacity of the soil or the exchangeable cation contents, also contribute to this axis. Second axis is interpretable in terms of a fertility and compaction gradient. The III axis is defined by the organic matter content, which negatively correlates with the soil structural instability. The ordination of the localities in the space defined by these axis shows that the III axis reflects the land-use related anthropization gradient, and therefore the accumulation of soil organic matter plays a key function in the recovery of the soil system after agricultural use in this area. These results are similar to those reported by other authors (Escarré et al, 1983, Puerto *et al.*,1990). The MDS technique gave us an equivalent picture for a three-dimension ordination. The value of stress obtained was of 0.154, which seems reasonable for interpretation.

The third set of analysis combined grassland soils with samples corresponding to the edaphic material cover of dumping sites (figure 2). Results show that the installation of waste disposal sites affects the soil system of these Mediterranean ecosystems in a different way. Indeed, the interpretation of the first axis of the PCA indicates that to the above mentioned granulometric gradient, a new one defined by the soil organic matter content and the structural instability and trophic degradation, is added. This resulted in an increase of the percentage of the variance absorbed from 21 to 24% of the total. The second axis (with a 19% of variance explained) is connected to the concentration of chlorides, sulphates and fluorides in soil, which increases in dumping site samples. Both gradients summarise some of the most common effects associated to anthropic impact: retardation of nutrient cycling processes, degradation of physical structure and salinity/toxicity problems.

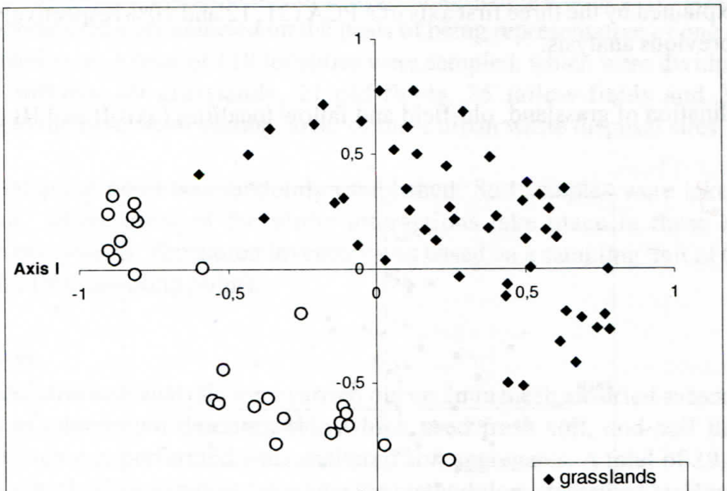
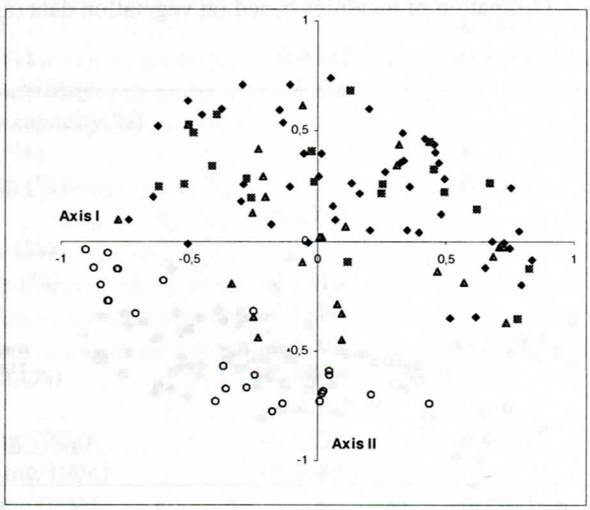


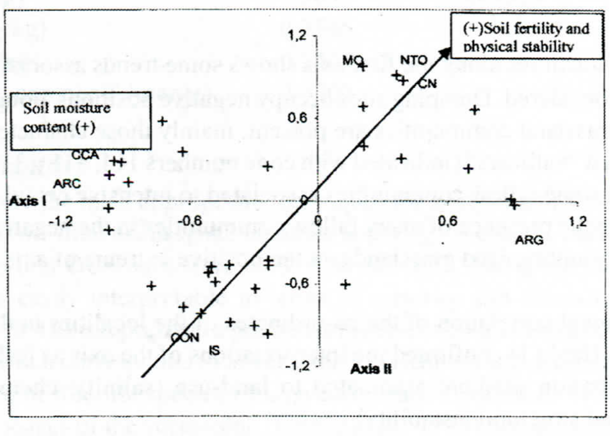
Figure 2. Ordination of grassland and dumping localities (axis I and II of PCA)

Figure 3 shows the results of the analysis carried out on the whole of the data set. The ordination enhances, again, the role of organic matter in the recovery of these systems after perturbation. Human activity also implies an increase in soil structural instability and trophic degradation index, as shown by axis II of the PCA. Results obtained by applying MDS were identical (stress value of 0.144).

Figure 3. PCA ordination of localities



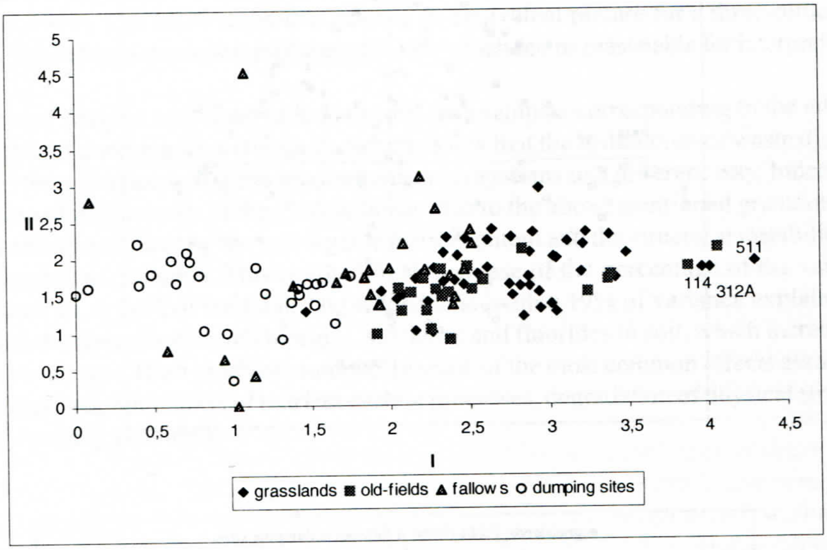
♦:grasslands; □:old-fields; Δ:fallows; o:dumping sites



Vegetation data

Of the three numerical techniques applied DCA proved to be the most adequate for analysing floristic composition data. Figure 4 shows the ordination of the 120 localities in the space defined by axis I-II of the DCA-ordination. They present eigenvalues of 0.55, 0.37 and 0.29 respectively. These high values indicate the importance of the associated gradients in the structure of these herbaceous plant communities.

Figure 4. DCA Ordination of localities based on vegetation data (axis I and II)



The ordination of localities along the first axis shows some trends associated to the different type of land-uses considered. Dumping sites occupy negative positions along the axis, while in the opposite site grassland communities are present, mainly those characterised by high soil water content, called “vallicars” (indicated with code numbers 114, 511 y 312A). Very close to the former we find some fallow communities associated to intensive cereal cultivation fields. It is also noticeable the presence of many fallow communities in the negative extreme of axis II and of some very anthropized grasslands in the positive extreme of axis III.

The study of the lineal correlation of the co-ordinates of the localities in the three axes with soil abiotic factors (table 1) confirmed the interpretations of the axis as follows:

- axis I: perturbation gradient associated to land-use (salinity, chemical degradation, compaction and structural instability)
- axis II: gradient related to alteration produced by agricultural practices of soil conditions (pH increase, P availability) as well as a gradient connected to the soil type (granulometric composition).
- axis III: gradient related to factors affecting main physiological requirements for plant growth (humidity, porosity and nitrogen content).

Table 1. Correlation coefficients between soil abiotic factors and DCA ordination axis based on vegetation data ($p<0.005$)

SOIL FACTORS	Axis I	Axis II	Axis III
- Bulk density	-0.3035		
- Clay (%)			-0.2637
- Silt (%)	-0.5243		
- Total sand (%)	+0.4214		-0.2952
- Fine sand (%)		-0.3885	
- Coarse sand (%)	+0.4942	-0.3240	
- Structural unstabilility	-0.4302		
- Water holding capacity(%)			-0.3249
- Wilting point (%)			-0.3522
- Coarse fraction (%)		-0.3019	
- Porosity (%)	-0.2679		
- Microporosity (%)			-0.3151
- Macroporosity (%)	-0.3410		
- Impermeability	-0.5284		
- pH	-0.5708	-0.5158	
- Organic matter (%)	+0.4544		
- N total (%)	+0.4612		-0.2956
- P available (mg/100g)	-0.2837	-0.4231	
- Na available (mg/100g)	-0.3085		
- K available (mg/100g)		-0.2965	
- Ca available (mg/100g)	-0.3635		-0.2594
- Mg available (mg/100g)			-0.2678
- Conductivity (μmho/s)	-0.4126		
- P total (mg/kg)	-0.3648	-0.3519	
- Mn total (mg/kg)	-0.3545		
- Zn total (mg/kg)	-0.3457		
- Sum cations : organic C (meq/g)	-0.5201		

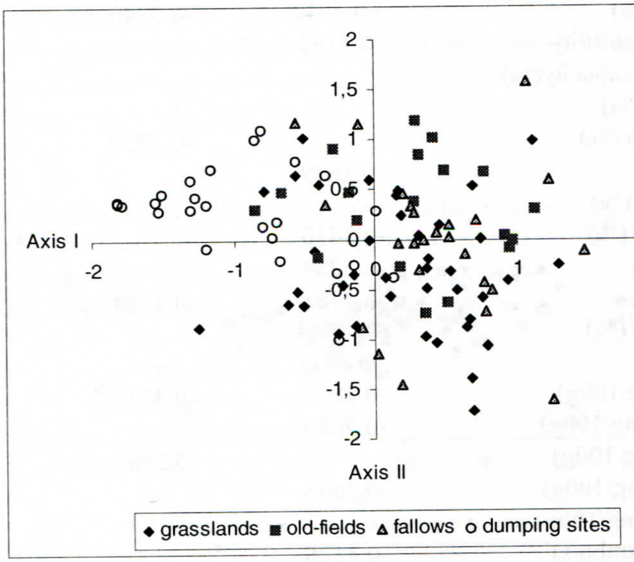
Nematode communities

DCA and MDS were the most appropriate techniques for analysing this data. Figure 5 shows the ordination in a two-dimension space obtained applying. The stress value is 0.16, while the eigenvalues of the first DCA axes were 0.68, 0.50 and 0.27. The space defined by the MDS ordination axes is easily interpretable in terms of maturity and diversity of the nematode communities. The first axis represents a gradient of species richness and diversity. The negative edge of the axis (which corresponds to lower values in richness and diversity) is characterised by a predominance of free-life species of high colonization potential. These populations are typical of the first stages of the succession (Goede *et al.,* 1993). In our study samples taken in dumping sites are associated to this area of the axis.

The second axis, which axis allows a slight differentiation of localities with regard to land-use, represents a double maturity gradient. The Maturity Index for free-life species increase towards the positive edge of the axis while that based on plant parasitic species increase in the opposite sense. This result outlines the different interpretation required by free-life and parasitic nematodes in these herbaceous communities dominated by annual species as is also mentioned by Freckman and Ettema (1993).

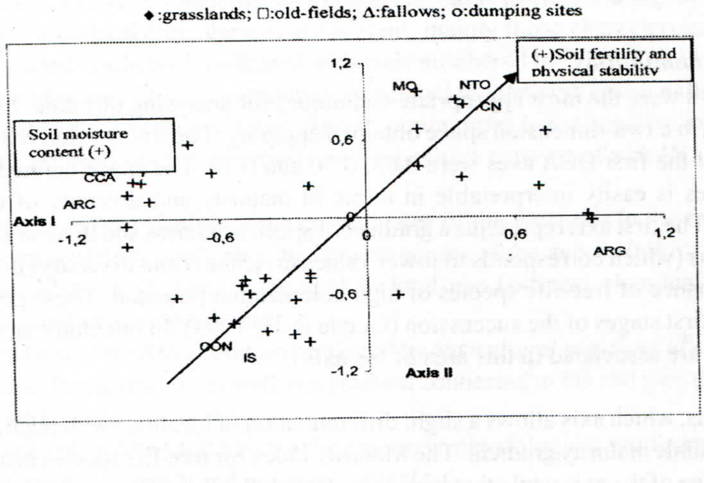
Figure 5. Ordination of localities based on biotic indices of soil nematode communities (MDS axis I and II)

A. Ordination of localities



B. Ordination of variables

◆:grasslands; □:old-fields; Δ:fallows; o:dumping sites



CONCLUDING REMARKS

Summarising, our results reveal that:

1. The analysis of soil abiotic factors showed that main differences among localities are due to, on the one hand, natural factors, which result in a humidity and fertility gradient connected to soil granulometric composition. On the other hand, as a result of human activity an organic matter content gradient has been generated, which is negatively connected to soil structure stability. Moreover, a salinity gradient is present with regard to dumping sites.

2. Plant communities actively respond to man-induced changes in the soil environment. However the use of vegetation composition as a tool for assessing these changes or the ecological conditions of a site requires more information about the ecophysiological response of the species to soil key-parameters. The lack of information is greater in the case of highly altered systems such as waste disposal sites.

3. Diversity and maturity indices related to soil nematode communities seem to be good indicators of anthropic impact in these mediterranean systems. However, MI is closely connected to radicular production in agrosystems, decreasing in favour of PPI index when root-mass production increases. This behaviour is opposite to what is expected if we interpret this evolution in terms of succession.

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